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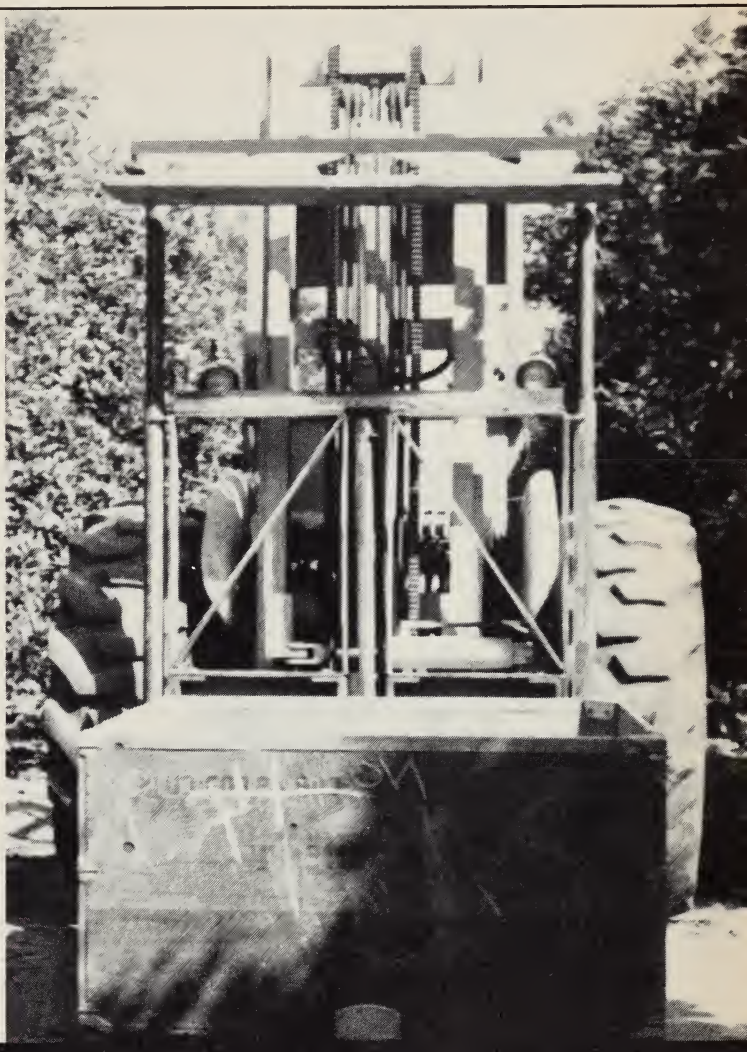

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OPERATIONAL AND ECONOMIC COMPARISON OF FORKLIFT AND TRAILER PALLET-BIN SYSTEMS WITH THE FIELD-BOX SYSTEM IN LEMON HARVESTING

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THIS BULLETIN

- analyzes the forklift and trailer pallet-bin systems and the conventional field-box system, and compares their efficiency and economic feasibility
- applies the break-even-point concept to picking-set-width in trees to minimize pickers walking time
- presents criteria for getting the most effective use from these systems under various orchard conditions

Although this publication is particularly concerned with problems involving a lower-yield harvest, it should be valuable for improving harvest efficiency of any tree crop.

Because of the increasing difficulty of obtaining labor to handle field containers, and because of needed infield and packing house economies, the citrus industry in fruit harvest has been converting from small field containers, which can be moved by workers, to larger bulk containers. Except for harvest operations where the volume yield in fruit per tree per pick was less than about four field-box equivalents (3115 cubic inches per field box) their conversion was a typical materials-handling problem. In these lighter yields, with which this study is concerned, use of the larger containers created additional problems since either additional picker walking or container handling was required to fill them. This paper compares the forklift and trailer pallet-bin systems with the conventional field-box system.

Assuming that additional fruit-carrying by pickers either must not occur or must be minimized and charged against the system, the within-orchard costs of the field-box system tended to be lower. This is because of its greater flexibility and reduced requirements in equipment and personnel. Of the two pallet-bin systems, the forklift system tended to be more economical if proper crew organization and operational procedures were achieved, but these conditions were harder to achieve with the forklift system. In all three systems, proper crew organization and operational procedures are required if significant saving in orchard harvesting costs are to be realized.

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OPERATIONAL AND ECONOMIC COMPARISON OF FORKLIFT AND TRAILER PALLET-BIN SYSTEMS WITH THE FIELD-BOX SYSTEM IN LEMON HARVESTING[1]

INTRODUCTION

In comparing the forklift and trailer pallet-bin systems with the conventional field-box system, it was found that the latter was the most flexible in adaptation to changing orchard conditions. This flexibility tended to reduce walking distances for pickers, particularly in light yields and with large crews. Overhead costs were also lower for this system, although pickers spend more time in emptying their bags of fruit and associated activities with the field-box system than they did with either of the pallet-bin systems. Within-orchard costs per box of fruit were lower in light yields for the field-box system than for pallet-bin systems, largely because of the greater overhead costs and the reduced flexibility of the latter. However, the lesser costs of the pallet-bin systems in transportation and packing house operations may more than offset these extra within-orchard costs.

The fork-lift system was much more sensitive than the trailer system to variations in volume of fruit per tree, average rates of picking, and overhead efficiency. Crew size tended to be a more limiting factor for the trailer system because of additional within-row walking required to empty the bags of fruit. Overhead charges were also greater for the trailer system. With proper crew organization and operational procedures for specific orchard conditions the forklift system tended to be more economical, but the ideal balance of crew organization and operational procedures is harder to attain with this system, particularly in orchards producing light yields.

In all three systems, proper crew organization and operational procedures are required if significant savings in orchard harvesting costs are to be realized.

Conditions of orchard harvest

Orchard harvesting operations are conducted under constantly changing conditions. Volume and location of fruit on trees, tree heights and spacing, as well as ground conditions are some of the many variables directly or indirectly affecting cost and efficiency of harvesting systems. Additionally, the harvesting crew must go to the crop rather than vice versa (as in the packing house) ; this means that rate of such movements must also be considered in measuring costs and efficiency. An efficient system under one set of orchard conditions may therefore prove unsatisfactory under other conditions. This means that average results from limited field tests of a system in a few orchards may be misleading if an attempt is made to apply such results to all orchards picked in a year's harvesting. Therefore, a systems-analysis must take crew and orchard variations into consideration. In anlyzing harvesting systems, the time factors effected by orchard and system variables must be identified and the effect of these variables on the time factors must then be measured. With such data the

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efficiency and cost of a system under a variety of crew and orchard conditions can be accurately projected.

Pertinent test information

The basic data obtained for this analysis (tables 1, 2, 8, 9, 16, 17, 18), were obtained in May and June, 1966, in three lemon orchards harvested by one of three systems:

- *the forklift system*, in which pallet-bins were placed and moved for the pickers by a conventional field-forklift truck.
- *the trailer system* (either drop-bed or step-up trailer), in which four pallet-bins were placed on trailers pulled by tractors, and into which the crew emptied fruit.
- *the field-box system* (in common use for lemons in Ventura County). Here, field containers are small enough to be handled by orchard workers when filled with fruit.

The capacity of the field bins was 22 FBE (field-box equivalent = 3,115 cubic inches); they were 30 inches high and outside dimensions were 47 inches by 47 inches. These dimensions are important because bin size and design effect the whole picking operation, including bag-emptying time. The pickers saved time in bag-emptying with the pallet-bin systems because they were largely relieved of the operations of leveling fruit, recording boxes picked, and getting and placing the boxes (table 1).

A crew usually consisted of about 16 pickers, a foreman, and a checker or tractor-forklift operator, or both. Average daily yield per tree ranged from 0.96 boxes to 2.90 boxes, with yields from 1.40 to 2.00 boxes per tree. Daily average boxes per hour per picker ranged from 3.43 to 6.21 (table 2). Tree spacing was usually about 20 feet. Equipment operators were judged "average" as systems were compared in relation to each other, and because the same workers were used in all comparisons their efficiency should be the same under all systems. In contrast to factory work, variations in orchard working conditions tend to make differences between worker efficiency relatively less important.

Certain assumptions were made when feasible. For example, the average rate of walk in moving from one picking set to another was assumed to be the same as the average rate of walk within each set in the orchard.

TABLE 1

TIME PER BAG REQUIRED FOR FRUIT-DUMPING ACTIVITIES IN ALL HARVESTING SYSTEMS*

Fruit-dumping activity	Time in various systems			
	Field box†	Pallet-bin		
		Forklift‡	Step-up trailer§	Drop-trailer‖
	minutes per bag¶			
Deposit fruit-field bag to field container.	0.16+	0.18++	0.12+	0.11+
Smooth fruit, set empty container, record	0.39++			
Step-up—ground to bin			0.06+	0.002+
Step-down—bin to ground			0.05+	0.02+
Record bag pick on bin by picker		0.15++		0.08+

* For all systems rate of walk (to box and to tree) averaged 225 feet per minute. It was assumed that average was same for all conditions.
† Average of 107 observations.
‡ Average of 25 observations.
§ Average of 86 observations.
‖ Average of 90 observations.
¶ + = standard error ±0.01; ++ = standard error ±0.02.

TABLE 2

AVERAGE HOURLY RATES OF PICKS AND EARNINGS OF PICKERS ON CREW DURING TEST PERIOD

System	Date (1966)	Average boxes per hour per picker	Average earning per hour (dollars)
Step-up trailer system	5-10	5.41	2.49
	5-11	5.58	2.57
	5-12	5.77	2.65
	5-13	5.61	2.41
Average		5.59	2.52
Forklift system	5-14	5.35	2.46
	5-16	5.04	2.17
	5-17	4.86	2.24
	5-18	5.23	2.41
	5-19	4.59	2.57
Average		5.01	2.34
Drop-trailer system	5-20	5.47	2.35
	5-21	4.95	2.27
	5-23	5.43	2.33
	5-24	4.57	2.98
	5-25	5.10	2.35
	5-26	5.38	2.31
	5-27	6.20	2.48
	5-28	4.14	2.11
	5-31	4.98	2.29
Average		5.13	2.31
Field-box system	6-1	4.82	2.46
	6-2	4.89	2.25
	6-3	4.45	2.23
	6-4	4.79	2.20
	6-6	4.65	2.14
	6-7	4.25	1.95
	6-8	3.81	1.79
	6-9	4.00	1.68
	6-10	4.14	1.90
	6-11	4.85	1.94
	6-12	3.96	1.66
Average		4.42	2.02

RELATION OF NUMBER OF TREES IN A SET, AVERAGE VOLUME OF FRUIT PICKED FROM A TREE, AND DISTANCE BETWEEN SETS, TO WALKING TIME

In "picking sets," which are a tree or trees being picked by one or more pickers, the average within-set round-trip walking time increases directly and uniformly as more rows of trees are added to the set (table 3). A picker's walking time to the set is prorated among all the bags of fruit he picks in the set in the same way that fixed costs are spread over all units of production. The time required for changing sets will, when prorated to each bag of fruit picked, vary directly with the time taken to change sets and inversely with the the number of bags picked at the set. But since total set-changing time is spread over all bags picked at the set, each bag

Table 3

WITHIN-SET ROUND TRIP WALKING TIME FOR BAG OF FRUIT*

Tree rows out from box row	Number of trees in set (box row in center of set)	Time for bag of fruit (minutes)
1	2	0.089
2	4	0.178
3	6	0.267
4	8	0.356
5	10	0.445
6	12	0.534
7	14	0.625
8	16	0.712
9	18	0.801
10	20	0.890
11	22	0.979
12	24	1.068
13	26	1.157
14	28	1.246
15	30	1.335
16	32	1.424
17	34	1.513
18	36	1.602

* 20-foot-spaced tree rows; walking rate 225 feet per minute.

picked at a set will reduce the set-changing time charged to all individual bags in progressively smaller amounts. This is a hyperbolic relationship in which changes in small volumes per set make a big difference, but equal changes in large volumes per set make little difference (table 4).

Mathematically a minimum total walking time for a bag of fruit occurs when the additional walking time needed to pick another bag of fruit within the set equals the set-changing time per bag.

Algebraically, this can be expressed in the form $vn = t/a\ n$, where

v = the average increased walking time per bag of fruit for each additional tree row out from the box row

n = the number of tree rows out from the box row

t = the total time to change picking sets down a box row

Table 4

AVERAGE BETWEEN-SET WALKING TIMES PRORATED TO EACH BAG PICKED FOR DISTANCES BETWEEN SETS AND BAGS OF FRUIT PER SET PER PICKER*

Bags per set per picker	Average between-set times							
	Distances between sets							
	100 feet	200 feet	320 feet	400 feet	480 feet	600 feet	640 feet	800 feet
	minutes							
½	0.889	1.778	2.844	3.556	4.267	5.333	5.689	7.111
1	0.444	0.889	1.422	1.778	2.133	2.667	2.844	3.556
2	0.222	0.444	0.711	0.889	1.067	1.333	1.422	1.778
3	0.148	0.296	0.474	0.593	0.711	0.889	0.948	1.185
4	0.111	0.222	0.356	0.444	0.533	0.667	0.711	0.889
5	0.089	0.178	0.284	0.356	0.427	0.533	0.569	0.711
6	0.074	0.148	0.237	0.296	0.356	0.444	0.474	0.593
7	0.063	0.127	0.203	0.254	0.305	0.381	0.406	0.508
8	0.056	0.111	0.178	0.222	0.267	0.333	0.356	0.444
9	0.049	0.099	0.158	0.198	0.237	0.296	0.316	0.395
10	0.044	0.089	0.142	0.178	0.213	0.267	0.284	0.356
11	0.040	0.081	0.129	0.162	0.194	0.242	0.259	0.323
12	0.037	0.074	0.119	0.148	0.178	0.222	0.237	0.296
14	0.032	0.063	0.102	0.127	0.152	0.190	0.203	0.254
16	0.028	0.056	0.089	0.111	0.133	0.167	0.178	0.222
18	0.025	0.049	0.079	0.099	0.119	0.148	0.158	0.198
20	0.022	0.044	0.071	0.089	0.107	0.133	0.142	0.178
22	0.020	0.040	0.065	0.081	0.097	0.121	0.129	0.162
24	0.019	0.037	0.059	0.074	0.089	0.111	0.119	0.148
30	0.015	0.030	0.047	0.059	0.071	0.089	0.095	0.119
36	0.012	0.025	0.040	0.049	0.059	0.074	0.079	0.099

* Walking rate, 225 feet per minute.

a = the number of bags of fruit for each picker for each additional tree row or rows for given distances out from the box row

Multiplying through the equation by n and dividing through by v changes the equation to

$$n^2 = t/a\,v \text{ or } n = \sqrt{t/a\,v}$$

The assumption is made that all movement time between sets is directly related to the distance between sets, although this is not strictly correct because there is some fixed time for set changing which is not related to the distance between sets (such as time taken by picker to get his ladder and water jug to move to the new set). This fixed time is not large enough to affect the formula significantly, but ignoring it would tend to make t too small for short moves between sets and too large for long moves between sets.

Formula terms as influenced by orchard, crew size, and management factors

In the above formula, the value of t (total time needed to change from set to set down a box row) is determined by the distance the pickers have to walk to do so and their rate of walk; walking distance is also related to tree spacing and the number of pickers working any box row. Thus, the only way t can be reduced without a similar reduction of a is to reduce the number of pickers going down a box row. For example. if no reduction is made in the number of pickers going down the box row and if not one but two workers are put in each set, t is reduced to one-half of its value, but so is a, so the value of the equation does not change. The value of a is a function of the absolute volume of fruit picked from the tree or trees, divided by the size of the picking bag. As the bags get larger the value of a gets smaller, and, if a larger bag did not slow down a picker's walking time proportionally to increase in bag size it would justify a wider picking set to save time.

An example of the use of the preceding formula would be in computing the minimum time relationship for a 30-man crew picking down the same box row, trees spaced 20 feet apart, with three bags as the average volume of friut per tree, one picker per set and with the set extending equal distances on each side of the box row. Thus, there would be 30 picking sets spaced 20 feet apart down the row and this means that on the average a picker would walk 600 feet in changing picking sets. If he walked 225 feet a minute it would take him 0.444 minute to walk 100 feet or 2.66 minutes to walk to the next set (which is t in the formula). There are two trees at given distances from the box row, one on each side of the box row, so a equals three bags times two trees, or six bags; v equals 20 divided by the average walking rate of 225 feet a minute or 0.089 minute. Therefore, in this case

$$n = \sqrt{6\,\frac{2.67}{\text{x}.089}} = \sqrt{4.981}$$

$$= n = 2.34 \text{ rows out.}$$

As it is not practical to pick fractional trees rows, the best picking set width for minimizing pickers' walking time would be two tree rows on each side of the box row, or a total picking set width of four tree rows. If (as noted) two pickers were at a set the value of t would be reduced by one-half but so would the value of a; thus, the picking-set-width would remain the same: four tree rows. In this case, the total average walking time per bag of fruit (from table 3) would be 0.178 minute for within-the-set walking and, with 12 bags per set (table 4), 600 feet between sets, 0.222 minute per bag for between-the-set walking time, or an average total walking time of 0.400 minute for each bag of fruit picked by the picker.

Crew organization as a factor in picker walking

A practical application of the formula used above would be in determining the cost in walking time resulting from different systems of crew organization. For example the best set-widths and total walking times per bag of fruit in orchards of different yield were computed by having the whole crew of 30 workers picking down the same box row (table 5). Computations were made, with the crew divided into three groups and each group working a separate box row. Both the best set-width in trees, and the total walking time have been reduced by dividing the crew into three separate groups. Differences in total walking time in the two methods of crew organization were computed (table 6) and the man hours saved for an 8-hour day were determined; the man-hours saved per day went up as the yield per tree went down, even though the assumed rates of pick in the low-yield orchard were greatly reduced. This data indicate that variations in crew organizations have a much greater effect on total saving in walking time for pickers in low-yield orchards than for pickers in high-yield orchards. It is also noteworthy that if the best set-width is used in the two situations described, the three picking groups will spread across the orchard only about 1½ times more than when the whole crew picks down the same box row.

Walking time as influenced by differences of fruit volume, distances between sets, and set-width

In figure 1, the departure of curves from each other indicates the effect distance between sets has upon the best set-width. There is accelerated increase in the best set-width as bags of fruit per picker in the outermost rows become progressively smaller and the ratios of best set-widths to increased distances between sets remain about the same. This indicates that proper set-width is much more important in light than in heavy yields.

Figure 2 shows cost in extra walking time as the volumes of fruit per tree go down and the distances between sets go up. Note that the slopes of the curves become progressively steeper as volume of fruit on the tree goes down. The three bags per tree curve goes from 0.18 minute at 100 feet between sets to 0.47 minute at 800 feet between sets, a 0.29 minute difference. The one-half box per tree curve goes from 0.44 minute at 100 feet between sets to 1.13 minutes at 800 feet between sets, a 0.69 minute difference. This indicates that more is gained by keeping crews small in box rows in low-

TABLE 5

EFFECT OF CREW DIVISION ON CREW'S WALKING TIME*

Crew division	Bags picked per tree	Best set width in tree spacing to minimize picker walking	Walking time†		Total time†
			Within sets	Between sets	
All pickers pick down same box row:	3	4	0.178	0.222	0.400
	2	6	0.267	0.222	0.489
	1	8	0.356	0.333	0.689
	½	10	0.445	0.533	0.978
Crew divided into three groups; ten pickers per box row:	3	2	0.089	0.148	0.237
	2	4	0.178	0.111	0.289
	1	4	0.178	0.222	0.400
	½	6	0.267	0.296	0.563

*Crew of thirty pickers; walking rate, 225 feet per minute; 20 feet by 20 feet tree spacing; box row down center of sets.

†Minutes per bag.

TABLE 6

SAVING IN MAN HOURS BY DIVIDING CREW INTO THREE PICKING GROUPS*

Bags picked per tree	Total walking time per bag picked†		Minutes saved per bag with 3 rows	Bags picked per hour by crew‡	Man hours saved per 8 hour day
	Crew in one row	Crew in three rows			
3	0.400	0.237	0.163	162	3.52
2	0.489	0.289	0.200	144	3.84
1	0.689	0.400	0.289	117	4 51
½	0.978	0.563	0.415	93	5.15

*Crew of thirty pickers; walking rate, 225 feet per minute; 20 feet by 20 feet tree spacing; box row down center of sets.

† Minutes per bag.

‡ Estimated from the lemon incentive system tables used in Ventura County and as related to the crew under observation.

yield than in high-yield orchards, since the number of pickers in a box row determines (along with tree spacing) the distance between sets.

From a practical standpoint, it may not be desirable to change the width of the picking set every time a change is indicated by a change in volume of fruit per tree or crew size. Table 7 was developed to analyse these relationships.

For any number of bags per tree there is a set-width in trees which give a good fit through the range of distances between sets; that is, four trees per set for three-bag trees, six trees per set for one-bag trees, and ten trees per set for one-half-

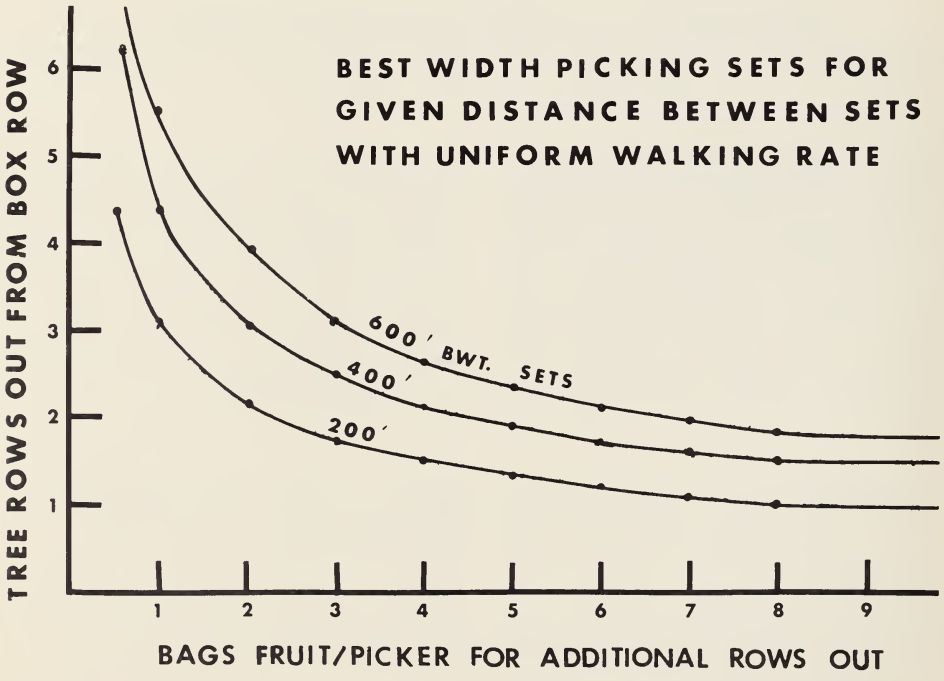

Fig. 1. Best width in picking sets in tree rows out from box row as determined by the number of bags of fruit per picker for each additional tree-row out from box row.

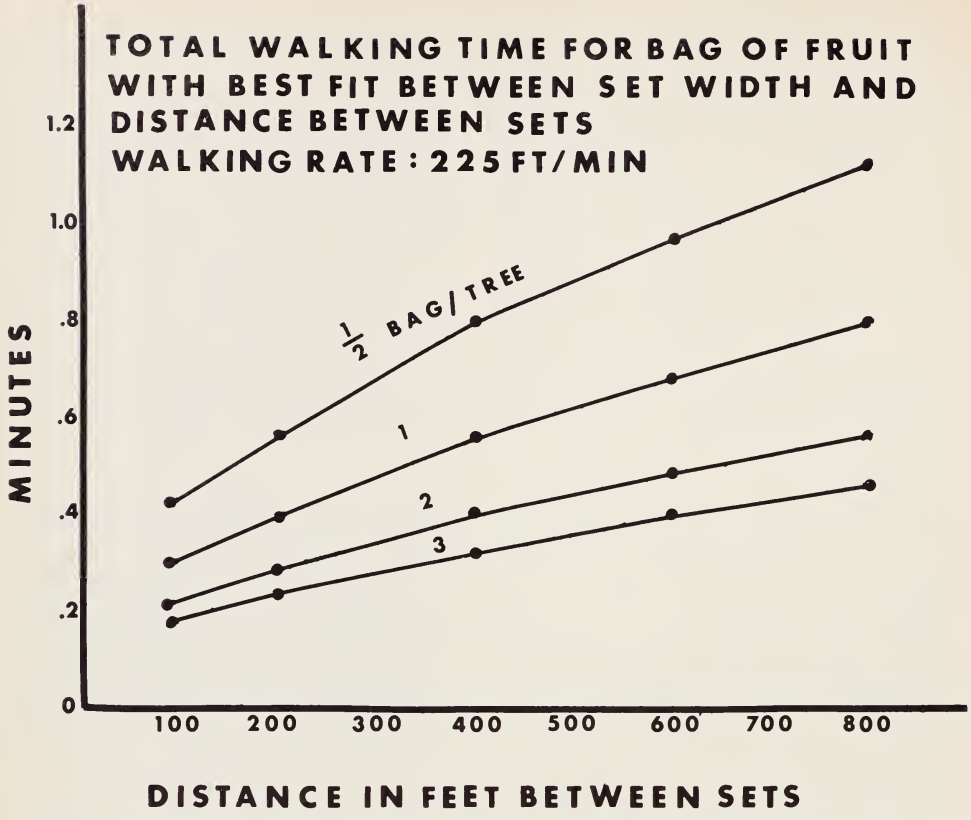

Fig. 2. Total walking time per bag of fruit with best fit between set-width and distance between sets. Walking rate is 225 feet per minute.

bag trees. When the distance between sets are short, a set-width can be found that can be applied to a range of tree volumes but not when the distance between sets become long. For 200 feet between sets, four trees per set give a good fit in the three figures; at 800 feet between sets there is no set-width satisfactory in all three cases and walking times for pickers can be greatly increased by using the wrong set-width. Finally, the figures (shown in table 7) indicate that proper set-width is important in low-yield orchards having long distances between sets, but that it is of minor importance in high-yield orchards.

EFFECT OF ORCHARD, CREW, AND EQUIPMENT ON THE FORKLIFT PALLET-BIN SYSTEM

The forklift—pallet-bin system of harvesting citrus is similar to the field-box system in that field containers are placed at a picking set and pickers deposit their fruit in them. It differs from the field-box system in that the forklift moves containers for the pickers. This, and the reduced time pickers spend doing incidental activities, reduces fruit-depositing time for pickers by about 0.37 minute per bag as compared to the field-box system. However, if the forklift performs inade-

TABLE 7

WALKING TIMES PER BAG OF FRUIT PICKED*

Bags picked per tree	Number of trees per set	Average within-set walking time	Average between-set walking time prorated to each bag picked				Total within-set and between-set walking time			
			Distance between sets							
			200 feet	400 feet	600 feet	800 feet	200 feet	400 feet	600 feet	800 feet
			minutes							
3	2	0.089	0.148	0.296	0.444	0.593	(0.237)	0.385	0.533	0.682
3	4	0.178	0.074	0.148	0.222	0.296	0.252	(0.326)	(0.400)	0.474
3	6	0.267	0.049	0.099	0.150	0.198	0.316	0.366	0.417	(0.465)
3	8	0.356	0.037	0.074	0.111	0.148	0.393	0.430	0.467	0.504
1	2	0.089	0.444	0.889	1.332	1.778	0.533	0.978	1.421	1.867
1	4	0.178	0.222	0.444	0.667	0.889	(0.400)	0.622	0.845	1.067
1	6	0.267	0.148	0.296	0.444	0.593	0.415	(0.563)	0.711	0.860
1	8	0.356	0.111	0.222	0.333	0.444	0.467	0.578	(0.689)	(0.800)
1	10	0.445	0.089	0.178	0.267	0.356	0.534	0.623	0.712	0.801
1	12	0.534	0.074	0.148	0.222	0.296	0.608	0.682	0.756	0.830
½	2	0.089	0.889	1.776	2.667	3.556	0.978	1.865	2.756	3.645
½	4	0.178	0.444	0.889	1.333	1.778	0.622	1.067	1.511	1.956
½	6	0.267	0.296	0.593	0.889	1.185	(0.563)	0.860	1.156	1.452
½	8	0.356	0.222	0.444	0.667	0.889	0.578	(0.800)	1.023	1.245
½	10	0.445	0.178	0.356	0.533	0.711	0.622	(0.800)	(0.977)	1.155
½	12	0.534	0.148	0.296	0.444	0.593	0.681	0.829	(0.977)	(1.126)
½	14	0.625	0.127	0.254	0.381	0.508	0.752	0.879	1.006	1.133

* Trees spaced 20 feet apart; trees in set in single row; box row through center of set; average walking rate 225 feet per minute; times in minutes; numbers in parentheses are minimum time values; one picker per set.

quately the whole system tends to break down.

If pickers deposit their fruit in bins along the box row (as in this study) forklift activity is largely confined to the box rows. This means that, for equal-size bins, the amount of work the forklift must perform to service the crew is largely a function of the variation in volume of fruit the crew is picking in any time interval, the average volume of fruit in a picking set, and the efficiency of any forklift-operator combination. The volume of fruit a crew is picking in equal time intervals is directly related to crew size and the average rate of pick of individual pickers. The average volume of fruit in a set is directly determined by the average volume of fruit per tree, and the number of trees in the set.

The amount of work the forklift must do (table 8) is directly and linearly related to rate of pick of the crew, but is not linearly related to the variation in volume of fruit deposited in the bins for a picking set. This is because the various operations of the forklift are affected in different ways by the variation of this volume factor. A change in volume of fruit along the box row will affect the amount of forklift movement involved in unloading empty bins from the truck, distributing empties between picking sets, placing fills by forklift for truck loading, and loading fills by the forklift on a truck, but it should not significantly affect fixed times such as engaging, placing, and releasing the empty and filled bins. From this and from other field observations it was estimated that the duration of these forklift operations will have a 25 per cent inverse-variation relationship to variation of fruit in the box rows.

The problem of moving partly-filled bins

The forklift operation, which is by far the most sensitive to changes in volume of fruit per set, involves moving partly filled bins to a new set for pickers. If volume of fruit per set exactly equals the capacity of the bin no extra moving of the bin is necessary; if volume pre set is one-half the capacity of the bin, one move is necessary (in our tests there were 0.77 moves per bin) ; if one-fourth the volume per set, three movements of the bin are necessary, and so forth. Because there are variations in volume per set in any orchard, and because set volume may not equal bin volume, some movement of bins will be necessary when the volume of fruit per set equals or exceeds the capacity of the bins, but forklift movement of bins should gradually decrease as the volume of fruit per set incerases over the capacities of the bins. (Here it was assumed that one extra move per four sets would be required when the average volume per set equaled that of the bin.)

Determining forklift efficiency

Total operational times were divided by 0.80 (table 9) on the assumption that if the forklift was busy on an average of more than 80 per cent of the time, bottlenecks in forklift service to the crew would occur. These figures were converted to the number of FBE the forklift can handle in an hour. From this the number of pickers the forklift can service at various average rates of pick and different given boxes per set can be computed. Average hourly rates of pick were computed for 3.1 boxes per hour, which is an estimated average rate of pick in a ½ box per tree orchard, 3.9 boxes per hour for a 1-box per tree orchard, 4.5 boxes per hour (which was the average rate of pick when trees averaged 1.8 boxes), and 5.4 boxes per hour for a 3-box-per-tree orchard. These estimates were made from the lemon incentive system tables used in Ventura County, and they reflect average rates of pick for lemons in the county in past years (Smith *et al.*, 1965). The values were then plotted and curves were drawn through the

TABLE 8

AVERAGE TIMES FOR FORKLIFT OPERATIONS IN FORKLIFT SYSTEMS

Forklift operation	Average times for forklift operations					
	Twenty-two field box equivalent bins‡			Eleven field box equivalent bins§		
	5.5 boxes per set	11 boxes per set	22 boxes per set	5.5 boxes per set	11 boxes per set	22 boxes per set
	minutes					
Unloading empty bins from truck*	0.84	0.67	0.50	0.76	0.60	0.45
Distributing empties between picking set*	1.44	1.15	0.86	1.30	1.03	0.77
Moving partly-filled bins for pickers†	9.09	2.33	0.76	2.09	0.68	—
Placing filled bins for truck loading*	2.46	1.97	1.48	2.21	1.77	1.33
Loading filled bins on the truck*	1.20	0.96	0.72	1.08	0.86	0.65
Receiving instruction*	0.62	0.50	0.38	0.62	0.50	0.38

* Assume 25 per cent direct variation in times between 11 boxes per set and 22 boxes per set and 11 boxes per set with 5.5 boxes per set.

† For test in twenty-two field box equivalent bins assume 0.77 moves per bin for 11 boxes per set, three moves per bin for 5.5 boxes per set, ¼ move per bin for 22 boxes per set; for 11 field box equivalent bins assume 0.77 moves per bin for 5.5 boxes per set, ¼ move per bin with 11 boxes per set, no moves per bin with 22 boxes per set.

‡ Test values on average of eleven boxes per set with adjustments for changed fruit volume per set.

§ Estimated values. These are the twenty-two field box equivalent bin values reduced by 10 per cent.

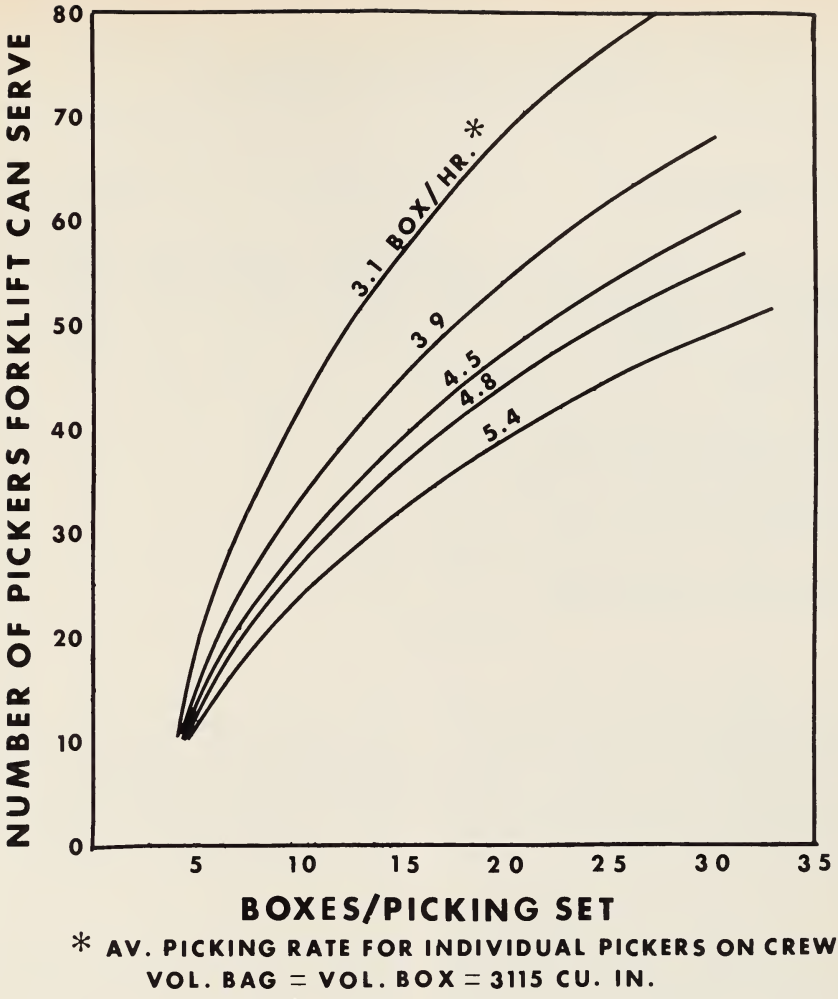

Fig. 3. Number of pickers forklift can serve as effected by average picking rates of individual pickers on the crew and bags of fruit per picking set.

plotted points; from this graph (fig. 3) one can determine the boxes per picking-set needed to insure adequate forklift service for different crew sizes at stated average rates of pick. (This is assuming that the forklift-operator combination is operating at the same efficiency as it did during the field test, and that the highway truck is loaded within the orchard.)

Importance of forklift efficiency

Forklift efficiency is an important factor in the success of the system, so the question arises as to the degree and nature of its importance. To answer this question, it was assumed that the forklift operator working during the field tests performed at average efficiency. His rate of work was then reduced by 20 per cent in one case and increased by 20 per cent in another case; this figure was used because in many tasks (including fruit picking), the standard deviation between individual workers is about 20 per cent from the average of all workers doing the same task (Wecheler, 1952). One plus or minus

Table 9

FORKLIFT EFFICIENCY AS INFLUENCED BY BIN SIZE AND VOLUME OF FRUIT PER PICKING SET

Efficiency factors	Values of efficiency factors					
	Twenty-two field box equivalent bins			Eleven field box equivalent bins		
	5.5 boxes per set	11 boxes per set	22 boxes per set	5.5 boxes per set	11 boxes per set	22 boxes per set
Total operation time per bin in minutes, excluding delays	15.65	7.58	4.70	8.06	5.44	3.58
Total operation time in minutes per bin with estimated delay time*	19.56	9.48	5.88	10.08	6.80	4.48
Total number of field boxes forklift can handle in one hour	67	139	224	65	97	147
Number of pickers forklift can serve at an average picking rate of 4.5 boxes per hour per picker	15	31	50	14	22	33
Per cent of forklift time assignable to movement of partially filled bins	58	31	16	26	12	——
Per cent of forklift time assignable to truck loading	19	31	37	32	39	44

*Total operation time divided by 0.80.

standard deviation from the average includes about 68 per cent of the workers; this means that when a worker is working 20 per cent below average only about 16 per cent of the workers are working slower than he is. For the worker who is 20 per cent above average, only 16 per cent of all workers are working faster than he is, so he is working at the 84th percentile for all workers doing that task.

The data in figure 3 were used to determine the number of trees per set needed to insure adequate forklift service for different numbers of pickers and yields per tree under test conditions. These values were then increased 20 per cent for the 16th percentile operator and reduced 20 per cent for the 84th percentile operator. By using the formula

$$n = \sqrt{\frac{t}{a\,v}}$$

the best number of trees per set for a picker were determined (table 10).

Table 10 shows the large number of trees per set needed for large crews, fast rates of pick, and small yields—even for the better forklift operator. (This is not uncommon in harvesting lemon crops.) Table 11 shows the effect on picker walking time from using a 16 percentile instead of an 84 percentile forklift operator. When the number of trees needed to insure adequate forklift service is equal to or less than the best number of trees per set for pickers for both the 16 and 84 percentile forklift operators, picker walking time is not influenced by use of less competent operators—who simply work a little harder than the better operators. When the number of trees per set needed to insure adequate forklift service exceeds the number best for pickers, set-widths must be such that adequate forklift service is insured. Here, the less skilled forklift operator causes pickers to walk more for a bag of fruit than the good operator does. For comparison the between-and within-set walking times are determined for pickers from tables 3 and 4, and the total walking times for pickers with good operator are subtracted from those with the poor operator. Table 11

TABLE 10

NUMBER OF TREES PER SET NEEDED TO INSURE ADEQUATE FORKLIFT SERVICE*

Pickers on crew	Trees per set for minimum operation								
	Three bags per tree			One bag per tree			One-half bag per tree		
	Best set width in tree spacing to minimize picker walking†	Sixteen percentile operator	Eighty-four percentile operator	Best set width in tree spacing to minimize picker walking†	Sixteen percentile operator	Eighty-four percentile operator	Best set width in tree spacing to minimize picker walking†	Sixteen percentile operator	Eighty-four percentile operator
	3.1 boxes per hour								
16	4	2	2	6	6	4	8	12	8
24	4	4	2	6	8	6	10	16	10
32	4	4	2	8	10	8	12	20	14
40	6	4	4	8	12	8	12	24	16
	3.9 boxes per hour								
16	4	4	2	6	8	6	8	14	10
24	4	4	2	6	10	6	10	18	12
32	4	4	4	8	12	8	12	24	16
40	6	6	4	8	16	12	12	32	22
	5.4 boxes per hour								
16	4	4	2	6	8	6	8	18	12
24	4	6	4	6	14	10	10	26	18
32	4	6	4	8	18	12	12	36	24
40	6	10	6	8	26	18	12	50	34

* Based on test forklift operator at 50 percentile efficiency.

† Values are determined by formula $n = \sqrt{\frac{t}{av}}$ which are rounded off and doubled because it was assumed that the box rows run down the center of the sets.

also shows the importance of efficient forklift service in keeping down walking time—note that for small crews and slow average rates of picks, efficient forklift service is not particularly important, but for large crews and fast rates of pick efficient forklift service becomes very important.

It is important to have efficient forklift operations for fast rates of pick and for low-yield picks. For 3-box-per-tree picks, pickers are not greatly penalized in walking time because of an inefficient forklift operator even with slower rates of pick and average-size crews. For fast pick and average-or large-size crews, however, an inefficient operator is economically disastrous. When the forklift system is used in citrus harvesting, an attempt should be made to match forklift operators of different efficiencies with proper crews and orchard variables so as to realize the maximum over-all efficiency of the total harvest operation.

The folklift system is basically one of machine placement and field-container movement, and the same principles would apply if a straddle carrier or other moving equipment was substituted for the forklift itself.

Effect of bin size on the forklift system

The size of the pallet bin used in the forklift pallet-bin system has an effect on the time involved in handling bins by forklift and on the operational characteristics of the system; these effects vary as the volume of fruit at a set varies. To illus-

TABLE 11

PICKER WALKING TIME PER BAG OF FRUIT (FORKLIFT SYSTEM) AS AFFECTED BY FORKLIFT OPERATOR EFFICIENCY, CREW SIZE, AND RATE OF PICK IN A 1-BOX PER TREE HARVEST

Pickers on crew	Trees per picking set required to minimize picker walking*	Picking operation serviced a 16-percentile operator				Picking operation serviced by an 84-percentile operator				Differences between times per bag for two types of operators
		Trees per picking set required for adequate forklift service	Walking time (minutes) per bag of fruit			Trees per picking set required for adequate forklift service	Walking time (minutes) per bag of fruit			
			Between-set	Within-set	Total		Between-set	Within-set	Total	
		3.1 boxes per hour								*minutes*
16	6	6	0.237	0.267	0.504	4	0.237	0.267	0.504	0.000
24	6	8	0.267	0.356	0.623	6	0.356	0.267	0.623	0.000
32	8	10	0.284	0.445	0.729	8	0.356	0.356	0.712	0.017
40	8	12	0.296	0.534	0.830	8	0.444	0.356	0.800	0.030
		3.9 boxes per hour								
16	6	8	0.178	0.356	0.534	6	0.237	0.267	0.504	0.030
24	6	10	0.213	0.445	0.658	6	0.356	0.267	0.623	0.035
32	8	12	0.237	0.534	0.771	8	0.356	0.356	0.712	0.059
40	8	16	0.222	0.712	0.934	12	0.296	0.534	0.830	0.104
		5.4 boxes per hour								
16	6	8	0.178	0.356	0.534	6	0.237	0.267	0.504	0.030
24	6	14	0.152	0.625	0.777	10	0.213	0.445	0.658	0.119
32	8	18	0.158	0.801	0.959	12	0.237	0.534	0.771	0.188
40	8	26	0.137	1.157	1.294	18	0.198	0.801	0.999	0.295

* Assume a single row of trees make up a picking set. Each picking set is in a single row of trees at right angles to the picking row.

trate this, simulated times were developed for the forklift functions when 11 FBE bins are used. In table 8, values for the 11 field-box-equivalent bins were computed by reducing the values for the 22 field-box-equivalent bins by 10 per cent on the assumption that a forklift would spend 10 per cent less time in handling individual 11 FBE bins than individual 22 FBE bins. (As values for the 11 FBE bins are not based upon actual field observations they should be used as comparisons of trends and effects in different bin sizes only, and not as measurements of actual differences.) The reduced values were recorded directly for all operations except the operation of "movement of partly-filled bins for pickers" which is greatly reduced by using the 11 FBE bin. Apparently, the number of movements per bin of the 11 FBE bin for 11-box sets is the same as for a 22 FBE bin in 22-box sets, and the same is true for the 11 FBE bin in 5.5-box sets as compared to the 22 FBE bin in 11-box sets. (The values in table 8 for movement of partly-filled bins by the forklift were calculated on this basis.)

Apparently, the forklift can serve a larger crew with the 22 FBE bins than with the 11 FBE bins (table 9), although the differences tend to disappear as the boxes per set become smaller. At 22 boxes per set, forklift capacity with 11 FBE bins appears to be only 66 per cent of capacity with the 22 FBE bins; at 11 boxes per set it is 70 per cent; and at 5.5 boxes per set it is 97 per cent of its capacity with the larger bins. This indicates that with smaller bins the system is less sensitive to changes in volume of fruit per set than it is with larger bins.

This is explained by the difference in the needed number of moves of partly-filled bins in the two bin sizes (table 8).

A comparison of the per cent movement of time of partly-filled bins for the two bin sizes in table 9 indicates that for larger bins—except where sets have many boxes of fruit—the movement of partly-filled bins is a major activity for the forklift, but for smaller bins this activity becomes important only when there are few boxes per set. The importance of this is that, when the movement of partly-filled bins become a major activity for the forklift, the forklift becomes closely tied to crew movement through the orchard and is not as free to perform other functions during the day. Also, with smaller bins (particularly in heavier yields) pickers can move to a new set and start filling an empty bin before the partly-filled bins are brought too them by the forklift to complete filling. This helps keep the forklift's nonproductive time to a minimum and helps the system operate smoothly.

The percentage of the time closely associated with or directly related to truck-loading of filled bins varies from 19 to 37 per cent for 22 FBE, and from 32 to 44 per cent for 11 FBE bins. In both cases the time chargeable to truck loading is high, which indicates that this function should be examined closely. A more efficient method should be substituted for the forklift in truck loading. This is particularly true when smaller bins are used, for with these the loading function dominates the system.

EFFECT OF CREW SIZE AND EQUIPMENT USE ON PICKER WALKING IN THE TRAILER SYSTEM

The trailer system forces within-row walking on the pickers because the bins are centrally located on trailers. This walking can be lessened by assigning more than one picker to each picking set, which leads to what is called "community" picking. Such bunching of pickers within picking sets reduces but does not eliminate all within-the-row walking, and for any equal bunching of pickers within-row walking varies directly with the size of the crew serviced by one trailer. Thus, crew size tends to be a more limiting factor here than in other systems—for example, if pickers are spread 400 feet along the box row, 0.8 of a minute per bag of fruit picked will be spent on just walking along the box row.

In our discussion of the formula on page 7 we observed that bunching of pickers in sets does not affect the total of the within-and between-set walking time per bag of fruit because as t is reduced (because of shorter distances between sets) a is also reduced by a proportional amount. This extra within-row walking does not affect the best set-width for the pickers, as it is related to crew size and organization only and is unrelated to the factors which determine the best set-width.

Effect on picker walking of using two trailers

Use of two trailers within a box row reduces the amount of within-row walking for pickers per box of fruit, but the amount of reduction is partly dependent upon the location of the trailers in relation to each other within the crew. For example, if two trailers are used and spaced one tree-row apart distances equal to two sets are not affected by extra walking time, but for the other sets the walking times of pickers increase directly and uniformly as the distance of their sets increase from the trailers. Table 12

TABLE 12

AVERAGE EFFECT ON PICKER WALKING BY LENGTH OF TRAILER MOVEMENT BETWEEN STOPS ALONG BOX ROW*

Length of trailer movement in rows (20 feet between rows)	Average extra walking for crew	Average walking per man along box row		Average extra round trip time per man along box row
		Average extra one-way walking distance per man along box row	Average extra round trip walking distance per man along box row	
	feet	*feet per man*		*minutes per picker*
1	6.6	0.66	1.32	0.006
2	6.6	0.66	1.32	0.006
3	20.0	2.00	4.00	0.018
4	26.6	2.66	5.32	0.024
5	46.6	4.66	9.32	0.041
6	60.0	6.00	12.00	0.053
7	86.6	8.66	17.32	0.077
8	106.6	10.66	21.32	0.095
9	140.0	14.00	28.00	0.124

* Computed for ten sets along box row.

shows the effect of this upon within-row walking distances and times for pickers working at equal given distances along the box row. If one trailer is one-fourth of the way and the other is three-fourths of the way down the line of pickers along the box row, the effect is to reduce total within-the-row walking times of the pickers by almost one-half. This relationship of trailers within the crew has the same effect upon within-the-row walking times for the pickers as would occur if the crew was divided into two groups and each one was then sent down different rows with one of the trailers. The advantage of sending the crew down two box rows instead of one is that between-set walking time is also reduced; as in the field box system, this may be a real advantage in light yields. The main disadvantage of the 2-row over the 1-row procedure is that three trailers are essential because pickers cannot be left without containers to empty their bags in while a trailer is roadsiding a load of full bins; another disadvantage is that a strain may be put on overhead personnel servicing the crew.

Effect on picker walking of distance of trailer movement

In the trailer system, consideration must be given to the frequency or distance of trailer movement. The minimum average crew walking time along the box row occurs when trailers are centered among the pickers, and even if trailers are located out a bit from this crew center the average walking distance per bag of fruit for the crew does not increase significantly. Mathematically, average crew-walking time per bag of fruit as the trailers depart by given increments from the crew center increases parabolically. This parabolic increase containues until the maximum rate of increase is reached as trailers leave the boundaries of either the first or last picking sets along the row. At this point the increase in the crew's average walking distance is directly proportional to the distance the trailers move away from the crew. When the trailers are moved ahead of the crew center and stopped and the crew moves by the trailers along the box row, the average walking distance to the trailers by the crew moves as described

TABLE 13

DISTANCES AND WALKING TIMES TO AND FROM SETS WITH TWO TRAILERS SPACED ONE TREE-ROW APART*

Spread of pickers along box row†	Walking distance		Walking time		
	Total within-row walking	Average walking distance along box row	One-way average walking time along box row	Round trip average walking time along box row	Round trip walking time from furthest sets
	feet		*minutes*		
2	0	0	0.00	0.00	0.00
4	50	12.5	0.06	0.12	0.27
6	130	21.7	0.10	0.20	0.44
8	250	31.2	0.14	0.28	0.62
10	410	41.0	0.18	0.36	0.80
12	610	50.8	0.23	0.46	0.98
14	850	60.7	0.27	0.54	1.15
16	1130	70.6	0.31	0.62	1.33
18	1450	80.6	0.36	0.72	1.50
20	1810	90.5	0.40	0.80	1.78

* Walking rate 225 feet per minute; 20 foot spacing of trees along rows.
† Measured in the number of tree rows along box row.

above. The average extra walking distance of the crew moving along the box row can be computed by dividing the total area under this parabolic curve by the number of picking sets for the crew. As table 12 shows, the average walking distance per picker does not increase by more than about 8 seconds in a 10-set crew even when the trailers are not moved until the crew has advanced nine sets along the row. Perhaps more important is the psychological effect upon individual pickers having the greatest walking distances when trailers are at the extreme positions (table 13).

The practical application of this is particularly useful when the trailer system has a high fixed time for each movement; this was the case with drop trailers, with a fixed time per move of 1.15 minutes which include both raising and lowering the trailers. For the step-up trailer, with no raising and lowering, this fixed time was only 0.30 minutes. Table 14 gives the average movement of a crew down a box row for different volumes of fruit per set and sizes of crew. Table 15 gives the average rate of movement for drop trailers tested for different movement distances when both fixed time and movement time are included. If two trailers are moved in increments of 40 feet (table 15) the two trailers can be moved ahead by one man at the average rate of only about 13.5 feet per minute. If two trailers are serving a 20-man crew, and if in addition the crew is in a yield of only 2 boxes per set, the movement of crew down the box row is 13 feet per minute, or one man would be spending all of his time moving trailers just to keep up with the crew. If trailers are moved in increments of 100 instead of 40 feet, only about one-half of a man's time would be involved in moving the trailers and the average walking distance would hardly be increased (table 12). This time saved in trailer movement is of particular importance if the man moving the trailer also has other duties. In order to greatly reduce this fixed time for trailer movement, and thus free the foreman or other non-picking field personnel for other duties, it might be wise to not lower bins on trailers to the

TABLE 14

AVERAGE RATE OF MOVEMENT OF CREW THROUGH ORCHARD ALONG BOX ROW FOR DIFFERENT SIZE CREWS AND DIFFERENT VOLUMES OF FRUIT PER PICKING SET*

Number of men in crew	Average rate of movement of crew through orchard along box row										
	Number of boxes of fruit in a picking set										
	1	2	3	4	5	6	8	12	16	20	24
	feet per minute										
10	13	7	4	3	3	2	2	1	1	1	0.6
20	27	13	9	7	5	4	3	2	2	1	1
30	40	20	13	10	8	7	5	3	2	2	2
40	53	27	18	13	11	9	7	4	3	3	2

*Assume average rate of pick of four boxes per hour and a twenty foot spacing between tree rows.

ground but to keep them high enough to allow clearance as the trailer moves along the row; to compensate for the extra height of fruit dump, shallower bins could be used.

The main advantages of the trailer system over the forklift system are that a skilled forklift operator is not required, and the system can better accommodate itself to rapid crew movement through the orchard (such movement usually occurs in light picks).

OTHER EFFICIENCY FACTORS

Reducing operation times

The various operations of the three systems (forklift or trailer pallet-bin, and conventional field-box) should be analysed separately to determine how operational procedures or equipment can be

TABLE 15

AVERAGE RATE OF MOVEMENT OF DROP-TRAILER AS EFFECTED BY DISTANCE OF A SINGLE MOVE

Distance of single move	Time factors in movement of drop-trailer down box row			Average rate of drop-trailer movement
	Movement time*	Fixed time†	Total time	
feet	*minutes*			*feet per minute*
20	0.16	1.15	1.31	15.3
40	0.33	1.15	1.48	27.0
60	0.49	1.15	1.64	36.6
80	0.65	1.15	1.80	44.4
100	0.81	1.15	1.91	52.3
120	0.98	1.15	2.13	56.3
140	1.14	1.15	2.29	61.1
160	1.30	1.15	2.45	65.3
180	1.46	1.15	2.61	68.9
200	1.63	1.15	2.78	72.0

*At 123 feet per minute.
† Includes time to get on and off and raise and lower trailer.

TABLE 16

TRAILER TEST TIME DATA FOR BIN HANDLING

Equipment activity	Average test times for one drop-trailer carrying four bins		
	Trailer activity		Forklift time in loading trailer
	Fixed time per load	Movement time per load	
	minutes per trailer		
Raise trailer	0.62		
Get on trailer or forklift	0.46*		0.15
Start trailer or forklift	0.51*		0.17
Move trailer to loading area		1.87	0.42
Release full bins	0.52		
Set trailer over blocks	0.73		
Adjust blocks	0.85		
Set full bins on blocks	1.25		
Bring empty bin to trailer			2.10
Load empty bin on trailer			2.78
Park forklift			0.39
Adjust blocks for next load	0.87		
Miscellaneous activity	0.79		
Trailer to crew		1.32	
Lower trailers at crew	0.20		
Totals	6.80	3.19	6.01

*Activity performed twice.

Other operations for system:

For forklift: 7 minutes to unload 12 empties from truck
12 minutes to stack 12 empty bins in loading area
18 minutes to load 12 full bins on truck

For trailer: 4.5 minutes within picking trailer movement for 3 moves
(1.15 minutes fixed time and 0.35 minutes variable time per move)

Total man minutes for bin for system is 8.2 minutes

changed to make the system more useable in the harvest operations.

Tables 8, 9, 16, and 17 give breakdowns of average times needed for important operations in the three systems. All of these times would change as a result of modifications of equipment or procedures or of change in orchard conditions. For example (table 16) the times needed for setting the trailer over blocks, adjusting blocks, setting bins on blocks, bringing empty bins to the trailer, and loading empties on trailers can be reduced or eliminated by improved equipment or procedures at the loading area. Improved efficiency of the trailer system in this area permits greater flexibility, tends to reduce costs, and allows nonpicking field personnel more time for other essential activities.

Comparison of fruit-dumping timed in the three systems

The effect a system has upon fruit-disposing time for a picker is important (see table 1 for comparisons of these times). Average net times for emptying bags were less in the trailer systems. This is particularly interesting when comparing forklift with trailer systems, as the same bins were used in both cases. The pickers seemed eager to get rid of the fruit and get away from the bins when trailers were involved; this is also probably why they took longer to record their bags of fruit picked (when required to do so) in the forklift system. In the step-up trailer procedure, net depositing times for pickers were slightly more than for drop trailers. With drop trailers, the pickers had about a 26-inch lift to get the bag over the bin

TABLE 17

COMPARISON OF TIMES FOR CONTAINER HANDLING

Container-handling activity	Within-system times		
	Field-box system	Forklift system	Drop-trailer system
	minutes per twenty-two field box equivalents of fruit		
Extra picker handling of field boxes	8.86		
Unloading empties from truck		1.34†	.58
Distributing empties in orchard	1.12*	1.15	
Bin movement along picking sets		2.33	1.12
Movement to loading area and releasing load			3.89
Stacking full and empty bins for truck loading		1.97	1.00
Loading full field containers on trucks	7.73	1.92†	1.50
Totals	17.71	8.71	8.09

* Time for three men.
† Time for two men.

rim as compared to about a 32-inch lift on the step-up trailers. With step-up trailers, pickers stepped up 20 inches in two steps before they emptied their bags into the bin, which is the reason they spent 0.09 of a minute more time getting on and off of the step-up trailer than they did with the drop-trailer.

In depositing fruit into field containers some pickers first unlatch their bags and then dump the fruit; others do both in one operation. When these activities were done separately in the forklift system, pickers averaged 0.135 of a minute to unlatch a bag and 0.106 of a minute to dump its fruit, a total of 0.241 of a minute. When done in one operation, average total time was 0.137 of a minute. When the same activities were done separately in the drop-trailer system, pickers averaged 0.074 of a minute to unlatch a bag and 0.065 of a minute to dump its fruit, a total of 0.139 of a minute. In one orange harvest operation in the San Joaquin Valley using the Pauley System (a rotating-bin on truck system), pickers averaged about 0.07 of a minute in emptying each bag of fruit into 24-inch-high bins. The shallower bins, which made a one-operation procedure easier, and the fact that the pickers had experience in emptying into field bins, are probably the reasons why this operation was done so much faster. A two-operation procedure is natural when emptying into conventional field boxes. Another disadvantage of the two-operation procedure is that in depositing fruit the picker usually rests the bag on the rim of the bin, and this may cause additional fruit damage.

In this study, latching the bag was not considered a part of the fruit depositing function because pickers normally did it while walking back to their picking sets. When they stopped to latch their bags, however, they averaged 0.152 of a minute in the forklift system and 0.077 of a minute in the drop-trailer system.

Effect in field-box position on fruit dumping

In the conventional field-box system, position of the field box in the stack appeared to have some effect upon the time the pickers needed to empty their bags of fruit. To empty bags of fruit if the field box was on the ground, pickers averaged 0.148 of a minute; if at the 2-box level, 0.146 of a minute; if at the 3-box level, 0.174 of a minute; and if at the 4-box level, 0.226 of a minute. One picker emptied his bag at the 6-box level by standing on another box; he took 0.70 of a minute. Above the 2nd-box level, pickers apparently experienced difficulty in emptying bags into the field boxes.

ECONOMIC COMPARISON OF FORKLIFT, DROP-TRAILER AND FIELD-BOX SYSTEMS

Economic comparisons of these three systems involves attention to the relative amount of overhead costs needed to serve the crews, and to the time taken for activities of the pickers not associated with within-tree picking. This time consists of time involved in depositing fruit into field containers and associated activities, and the time needed for within-the-orchard walking for each bag of fruit picked. The value placed on any time lost or saved by pickers in these within-the-orchard times is computed at average estimated picker costs of $2.25 per hour, plus 25 per cent for fringe wage benefits and costs to the management, or $2.81 per hour. Table 18 gives breakdown of the estimated fixed and variable costs of within-field equipment used in the three systems, exclusive of the field containers.

Determination of Costs

The initial cost of the forklift is the estimated cost given by packing-house officials, and the tractor's initial cost is that of a model judged adequate for the trailer pallet-bin system. The initial cost of the drop-trailer is the quoted price for those trailers. The power unit for the trailer (cost, $290) and the tires (cost, $43 each) have a life of 5 years (at 8 hours a day) and 7 months a year, respectively, and therefore these costs were subtracted from the selling price of the trailers and written off under variable costs. (*The 1966 Agricultural Engineers Yearbook's* section on farm machinery costs was used as a guide in computing the fixed and variable costs of the equipment.) In the trailer system it was assumed that the forklift would be used only about one-third of the time, so one-third of the variable costs for the forkift pallet-bin system were used.

Non-picking operating costs of the systems

Table 19 gives estimated non-picking-crew operating costs. In the drop-trailer pallet-bin system it was assumed that

TABLE 18

ESTIMATED OPERATING COST OF EQUIPMENT IN PALLET-BIN SYSTEMS

Nature of cost	Estimated machine operating costs			
	Forklift in forklift system*	Forklift in trailer system†	Tractor in trailer system‡	Trailer in trailer system§
	dollars per hour			
Fixed costs:				
Depreciation	0.63	0.63	0.30	0.06
Interest	0.18	0.18	0.07	0.03
Fixed annual maintenance	0.05	0.03	0.02	0.01
Insurance	0.05	0.05	0.02	0.01
Variable costs:				
Maintenance due to operation	0.20	0.06	0.10	0.09
Fuel	0.34	0.11	0.11	
Engine oil	0.02	0.01	0.02	
Hydraulic oil	0.01	0.01		
Total machine costs	1.48	1.08	0.64	0.20

* Initial cost $6,800. Used for both within-field and truck-loading operations.
† Initial cost $6,800. Used only for truck-loading operations.
‡ Initial cost $2,800. Used to pull trailer.
§ Initial cost $1,104.

TABLE 19

ESTIMATED NON-PICKING OPERATING COST OF FORKLIFT, TRAILER AND FIELD-BOX SYSTEMS

Cost factors	Estimated crew non-picking operating cost for pallet-bin system*	
	Forklift system	Trailer system
	dollars per hour	
Forklift	1.48	1.08
Tractor		1.28†
Trailer		.40†
Crew foreman	3.18	3.18
Machine operator	2.93	2.93
Total crew non-picker cost (hour)	7.59	8.87

* For field-box system these costs include the crew foreman at $3.18 per hour plus $0.02 per box, swamper costs. Total costs thus equals $3.18 per hour plus $0.02 per box.
† For two operators.

each crew would need two tractors and two trailers. The crew foreman's wages were $2.45 per hour, plus 30 per cent for fringe wage benefits and costs to management, such as accident insurance, etc.; machine operator's wages were $2.25 per hour plus 30 per cent for fringe wage benefits and costs. Swamping costs for the standard field-box system were assumed to be 2 cents a box.

The crew's estimated non-picking operating costs are much lower in the field-box system than in the other two systems because in the former there is no need for expensive within-orchard equipment —the small field-containers allows pickers to do most of their own container moving. In this analysis, swamping costs are considered fixed per box and not fixed per crew as are true overhead costs. This is especially true in the forklift system. Here, loading full bins on the truck by forklift decreases the capacity of the forklift to service the crew, and this may show up indirectly by requiring more within-orchard walking by the picking crew (within-orchard loading of the highway truck is assumed in the forklift system). From the field test it appears that where fruit volume is low (compared, that is, to most other tree crops) the forklift cannot satisfactorily service the crew, roadside the filled bins, and load the trucks; therefore, the only alternative is within-orchard loading of the trucks. In the drop-trailer system it is assumed that the machine operator will have sufficient time to help load the trucks at roadside, and that while he is away from the picking operation the foreman can take over the functions of the machine operator.

The principal advantages of the pallet-bin systems over the field-box system in the harvest operation are: reduced amount of time needed by the pickers to dump their fruit—about 0.4 of a minute saving, and elimination of swamping (i.e. hand-loading of filled field-containers on trucks). These factors are used to offset the increased fixed overhead costs and, sometimes, the cost of extra walking that pickers do in the pallet-bin systems.

Differences in orchard and crew relationships between systems

The nature of orchard and crew relationships which force crews to walk more is different in the forklift than in the trailer system. In the former, capacity of the system to adequately service the crew is limited and when it is exceeded (either because of volume of fruit picked or because of fast crew movement through a low-yield orchard) adjustments must be made in the system by forcing more

walking on the crew to reduce work for the forklift. The trailer system can service the crew over a wide range of production and movement rates, but because trailers force all pickers to bring their fruit to a single location, extra within-row walking is necessary. Thus there is considerable within-row walking when trailers in one location service a crew picking over a large area. In a sense, crew-servicing capacity is the limiting factor for the forklift pallet-bin system, while crew size is the limiting factor for the trailer system.

Pallet-bin systems can be compared to field-box systems in two ways with regard to within-the-orchard walking. The first way is to assume that in the field-box system the crew is divided into units of about ten men, with each man picking down separate box rows. Here, the average within-and between-set walking time per bag of fruit for 3-bag trees is 0.787 of a minute regardless of crew size; 0.950 of a minute for 1-bag trees; and 1.113 minutes for ½-bag trees, regardless of crew size. The second way is to assume that in the field-box system all pickers on the same crew pick down 1 box row at a time, regardless of crew size. For pallet-bin systems, the assumption is that the whole crew will pick down the same box row at the same time. The reason for this is the greater difficulty of breaking up the pallet-bin systems crew into smaller units.

The degree to which crew size and number of bags of fruit per tree affects the walking time per bag of fruit can be large where there are large crews and low yields (table 20). Such differences have the same effect on all the systems—

TABLE 20

WALKING TIMES PER BAG OF FRUIT FOR THE FIELD-BOX SYSTEM AS INFLUENCED BY CREW SIZE, BAGS PER TREE, AND CREW ORGANIZATION*

Number of pickers along row	Best set width in tree spacings to minimize picker walking‡	Walking times per bag of fruit†				
		Within-set walking time	Between-set walking time	Total walking and fruit dumping time		Extra walking time for all pickers in same row
				All pickers in same row	10 pickers per box row	
	feet			*3 bags per tree*		
16	4	0.178	0.119	0.847	0.787	0.060
24	4	0.178	0.178	0.906	0.787	0.119
32	4	0.178	0.237	0.965	0.787	0.178
40	6	0.267	0.198	1.015	0.787	0.228
				1 bag per tree		
16	6	0.267	0.237	1.054	0.950	0.104
24	6	0.267	0.356	1.173	0.950	0.223
32	8	0.356	0.356	1.262	0.950	0.312
40	8	0.356	0.444	1.350	0.950	0.400
				½ bag per tree		
16	8	0.356	0.355	1.261	1.113	0.148
24	10	0.445	0.426	1.421	1.113	0.308
32	12	0.534	0.474	1.558	1.113	0.445
40	12	0.534	0.592	1.676	1.113	0.563

* One picker per set; trees 20 feet apart; walking rate 225 feet per minute; average fruit dumping time 0.55 minutes.
† Minutes per bag.
‡ Values are determined by formula $n = \sqrt{\frac{t}{av}}$ (rounded off and doubled because it was assumed that the box rows run down the center of the sets).

TABLE 21

WALKING AND TOTAL FRUIT-DEPOSITING TIMES PER BAG OF FRUIT FOR FORKLIFT AND FIELD-BOX SYSTEMS AS INFLUENCED BY CREW SIZE SET-WIDTH, NUMBER OF TREES, AND NUMBER OF BAGS PER TREE*

Number of pickers	Best set width in tree-rows to minimize picker walking†	Minimum number of trees per set necessary for adequate forklift service	Best number of trees per set for system	Walking time for bag of fruit‡		Total walking and fruit-dumping time per bag in forklift system‡	Increased walking and fruit-dumping time per bag in field-box system§	
				Within-set walking time	Between-set walking time		Field box, approximately 10 men per row‖	Field box, all crew same row
				3-bags per tree; picking rate 5.4 boxes per hour				
16	4	3	4	0.178	0.119	0.477	0.310	0.370
24	4	4	4	0.178	0.178	0.536	0.251	0.370
32	4	5	6	0.267	0.158	0.605	0.182	0.360
40	6	7	8	0.356	0.148	0.684	0.103	0.331
				1-bag per tree; picking rate 3.9 boxes per hour				
16	6	6	6	0.267	0.237	0.684	0.266	0.370
24	6	8	8	0.356	0.267	0.803	0.147	0.370
32	8	10	10	0.445	0.284	0.909	0.041	0.353
40	8	13	14	0.625	0.254	1.059	−0.109	0.291
				½-bag per tree; picking rate 3.1 boxes per hour				
16	8	10	10	0.445	0.284	0.909	0.204	0.352
24	10	12	12	0.534	0.356	1.070	0.043	0.351
32	12	16	16	0.712	0.356	1.248	−0.135	0.310
40	12	20	20	0.890	0.356	1.426	−0.313	0.250

* Two pickers per set; trees 20 feet apart; walking rate 225 feet per minute; average fruit dumping time 0.180 minutes.

† Values are determined by formula $n = \sqrt{\frac{t}{av}}$ (rounded off to whole number of trees and doubled because it was assumed that the box rows run down the center of the sets).

‡ Minutes per bag.

§ As compared with forklift; time is in minutes per bag.

‖ Values computed on the basis of 10 pickers to a box row.

TABLE 22

COST AND TIME COMPARISONS OF FORKLIFT AND FIELD-BOX SYSTEMS WITH VARIOUS CREW SIZES AND PICKING RATES UNDER THREE YIELD CONDITIONS AND TWO CREW DEPLOYMENTS

Number of pickers	Boxes picked by crew in 1 hour (both systems)	Forklift saving in minutes per box picked†	Cost comparisons of forklift and field-box systems*		
			Forklift fixed overhead minus dollars saved per hour‡	Field box fixed hourly overhead plus swamper costs‡	Saving per box with forklift systems§
			3 bags per tree; picking rate 5.4 boxes per hour‖		
16	86.4	0.310	6.34	4.91	−1.7
24	129.6	0.251	6.07	5.77	−0.2
32	172.8	0.182	6.12	6.64	+0.3
40	216.0	0.103	6.55	7.50	+0.4
			1 bag per tree; picking rate 3.9 boxes per hour‖		
16	62.4	0.266	6.81	4.43	−3.8
24	93.6	0.147	6.95	5.05	−2.0
32	124.8	−0.041	7.35	5.68	−1.3
40	156.0	−0.109	8.39	6.30	−1.3
			½ bag per tree; picking rate 3.1 boxes per hour‖		
16	49.6	0.204	7.12	4.17	−5.9
24	74.4	0.043	7.44	4.67	−3.7
32	99.2	−0.135	8.22	5.16	−3.1
40	124.0	−0.313	9.41	5.66	−3.0
			3 bags per tree; picking rate 5.4 boxes per hour¶		
16	86.4	0.370	6.09	4.91	−1.4
24	129.6	0.370	5.34	5.77	+0.3
32	172.8	0.360	4.68	6.64	+1.1
40	216.0	0.331	4.24	7.50	+1.5
			1 bag per tree; picking rate 3.9 boxes per hour¶		
16	62.4	0.370	6.51	4.43	−3.3
24	93.6	0.370	5.97	5.05	−1.0
32	124.8	0.353	5.53	5.68	+0.1
40	156.0	0.291	5.46	6.30	+0.5
			½ bag per tree; picking rate 3.1 boxes per hour¶		
16	49.6	0.352	6.77	4.17	−5.2
24	74.4	0.351	6.37	4.67	−2.3
32	99.2	0.310	6.15	5.16	−1.0
40	124.0	0.250	6.14	5.66	−0.4

* Fixed overhead costs: forklift $7.59 per hour; field box $3.10 per hour.
† See table 18, columns 8 and 9.
‡ Expressed as dollars per hour.
§ Expressed as cents per box. Minus sign indicates a higher cost for forklift system and plus sign indicates a lower cost.
‖ Computations based on ten pickers per box row in field-box system.
¶ All pickers down same row in field-box system.

inevitably there is extra walking time per bag of fruit when the whole crew is forced to pick down the same box row.

Table 21 shows, among other things, the minimum number of trees needed per set for adequate forklift service. When these values were larger than the best number of trees per set for the picker, they had to be used to compute within- and between-set walking time per bag of fruit for the forklift to keep up with the crew. The total of these two walking times then will be larger than the same times involved in the field-box system, and this will result in the reduction in times saved in column 9 to values less than 0.370 of a minute, the saving in the forklift system in emptying picking bags. The reduced times in column 8 (in comparison with column 9) reflect reduction in compari-

TABLE 23

TIME COMPARISONS OF DROP-TRAILER AND FIELD-BOX SYSTEMS HAVING DIFFERENT CREW SIZES AND TREE YIELDS*

Number of pickers	Best set width in tree spacings to minimize picker walking†	Walking time per bag of fruit‡			Total walking and fruit-dumping time of pickers in drop-trailer system†	Increased picker walking and fruit-dumping times of pickers in field-box over drop-trailer system‡	
		Within-set walking time§	Walking time along box row	Between-set walking time		Field box: approximately 10 men per row‖	Field box: all crew on same box row
		3 bags per tree; picking rate 5.4 boxes per hour					
16	4	0.178	0.120	0.119	0.567	0.220	0.280
24	4	0.178	0.200	0.178	0.706	0.081	0.200
32	4	0.178	0.280	0.237	0.845	−0.058	0.120
40	4	0.178	0.360	0.296	0.984	−0.197	0.031
		1 bag per tree; picking rate 3.9 boxes per hour					
16	4	0.178	0.120	0.356	0.804	0.146	0.250
24	8	0.356	0.200	0.267	0.973	−0.023	0.200
32	8	0.356	0.280	0.356	1.142	−0.192	0.120
40	8	0.356	0.360	0.444	1.310	−0.360	0.040
		½ bag per tree; picking rate 3.1 boxes per hour					
16	8	0.356	0.120	0.356	0.982	0.131	0.279
24	8	0.356	0.200	0.533	1.239	−0.126	0.182
32	12	0.534	0.280	0.474	1.438	−0.325	0.120
40	12	0.534	0.360	0.593	1.637	−0.524	0.039

* Four pickers per set; trees 20 feet apart; average fruit dumping time 0.150 minutes per bag; walking rate 225 feet per minute.

† Values are determined by formula $n = \sqrt{\frac{t}{av}}$ which are doubled and rounded off in increments of four since community picking with four pickers per set is used to keep walking time along box row to a minimum.

‡ Minutes per bag.

§ See also table 2.

‖ Values are computed on the basis of ten pickers per row.

sons with the field-box system when crews in the field-box system are divided into the groups of 10 pickers for box-row picking.

Economic comparisons of systems

Table 22 shows costs comparisons of forklift and field-box systems, first with about 10 pickers per box row in the field box system, and then with all pickers in both systems picking down the same box row. The last column shows a progressively poorer saving in the forklift system as the yields get lower. This condition results from two things: (1) the smaller volume of fruit picked in low yields increases the harvesting costs of the forklift system more because of its higher fixed overhead costs and 2) the greater discrepancy in the lower yields between the best number of trees per set for pickers and the number of trees per set needed for adequate forklift service. The poorer saving in the upper part of the table for the forklift system is a result of the saving in walking for the pickers in the field box system when the rows are divided into smaller groups.

When the whole field-box crew picks down the same row, the saving in minutes with the drop-trailer pallet-bin system remains about the same for the different yields for equal crews sizes (table 23). As crew size goes up the saving per bag goes down because of increased within-row walking to empty fruit from bags. (The slight irregularity in the comparisons in tables 22 and 24 is due to the wider increment adjustments used in the trailer systems for picking set-widths.)

TABLE 24

COST AND TIME COMPARISONS OF TRAILER (DROP-BED) AND FIELD-BOX SYSTEMS AT VARYING CREW SIZES AND PICKING RATES UNDER THREE YIELD CONDITIONS AND TWO CREW DEPLOYMENTS

Number of pickers	Boxes picked by crew in 1 hour (both systems)	Saving in minutes per box picked in trailer system†	Costs comparisons of trailer and field-box system*		
			Trailer: fixed overhead minus dollars saved per hour‡	Field box: fixed overhead plus swamper costs‡	Saving per box in trailer system§
			3 bags per tree; picking rate 5.4 boxes per hour‖		
16	86.4	0.220	7.98	4.91	−3.6
24	129.6	0.081	8.38	5.77	−2.0
32	172.8	−0.058	9.34	6.64	−1.6
40	216.0	−0.197	10.86	7.50	−1.6
			1 bag per tree; picking rate 3.9 boxes per hour‖		
16	62.4	0.146	8.44	4.43	−6.4
24	93.6	−0.023	8.97	5.05	−4.2
32	124.8	−0.192	9.99	5.68	−3.5
40	156.0	−0.360	11.50	6.30	−3.3
			½ bag per tree; picking rate 3.1 boxes per hour‖		
16	49.6	0.131	8.57	4.17	−8.9
24	74.4	−0.126	9.31	4.67	−6.2
32	99.2	−0.325	10.38	5.16	−5.3
40	124.0	−0.524	11.91	5.66	−5.0
			3 bags per tree; picking rate 5.4 boxes per hour¶		
16	86.4	0.280	7.74	4.91	−3.3
24	129.6	0.200	7.66	5.77	−1.5
32	172.8	0.120	7.90	6.64	−0.7
40	216.0	0.031	8.56	7.50	−0.5
			2 bags per tree; picking rate 4.8 boxes per hour¶		
16	62.4	0.250	8.14	4.43	−5.9
24	93.6	0.200	7.99	5.05	−3.1
32	124.8	0.120	8.17	5.68	−2.0
40	156.0	0.040	8.58	6.30	−1.5
			½ bag per tree; picking rate 3.1 boxes per hour¶		
16	49.6	0.279	8.22	4.17	−8.2
24	74.4	0.182	8.24	4.67	−4.8
32	99.7	0.120	8.31	5.16	−3.2
40	124.0	0.039	8.64	5.66	−2.4

* Fixed overhead costs: trailer system $8.87 per hour; field-box system $3.18 per hour.
† See tables 20, columns 7 and 8.
‡ Expressed as dollars per hour.
§ Expressed in cents per box. Minus sign indicates a higher cost for the trailer system.
‖ Computations based on ten pickers per row in field-box system.
¶ All pickers down same row in field-box system.

Table 24 shows that the drop-trailer pallet-bin system is less economical for low-yield trees because the smaller volumes of fruit being picked in this system cannot make up for the system's higher overhead costs.

DISCUSSION AND CONCLUSIONS

Table 22 and 24 indicate that the forklift system is more economical than the trailer system, but the cost differences between these systems are not great enough to preclude use of the trailer system under certain conditions—for example, in some orchards tree spacing may be too close for forklifts, or the soil condi-

tions might not be proper for their use. Community (trailer) picking also affects each picker's motivation.

Tests have shown that pickers appeared to be more highly motivated to pick fast with a trailer system, but this motivation could lessen in time. Crew morale appeared to be quite variable during these tests, and one of the days when the crew morale seemed the lowest was during drop-trailer system tests. On the first Monday after completing the drop-trailer tests, with the crew back on the field-box system, pickers were asked for their opinion of the trailer pallet-bin system. Opinions ranged from favorable to neutral. Some pickers felt that they were being pushed more in community picking, and that as a result they picked more fruit. According to the crew foreman, the principal disadvantage of the trailer system was that when he was tied to the trailers as a checker, etc. he was not able to check trees and the picker's work.

Picking is significantly slower in the field-box system than in the pallet-bin systems, but the differences are not significant when the extra time needed to dump fruit is taken out of the conventional field-box system. But if the rates were significantly different, differences could be caused by changed orchard conditions or other factors and not by system differences. Consequently, over-all rate differences are usually not reliable indicators of real differences. The Tree Production Incentive Wage System used in lemons in Ventura County eliminates about 50 per cent of the variance in earnings due to orchard conditions, but the unadjusted variance is still very high. For example, in one analysis made based on 1963 bracero data, the crews' average daily earnings varied in a range of about 40 per cent; this was apparently caused by constantly-changing orchard conditions which were not adjusted for by the Wage System, and much of the variation could be ascribed to such changes.

Under actual operating conditions it is much easier to predict the performance of the trailer than the forklifting system, particularly where there are light yields. This is because factors affecting trailer operation (such as crew size) are easy to measure or predict while the factors affecting forklift operation are much harder to predict, (such as average rate of pick on any particular day, or average volume of fruit per tree) ; and errors in predicting these factors may cause breakdowns in the forklift operation.

The assumptions made in this study may not be reliable under extreme conditions. In the forklift system, for example, where there are large crews and light yields forklifting results in very wide picking sets with consequent longer full-bag carry; this may cause excessive fatigue to pickers and thus make the system unsatisfactorily.

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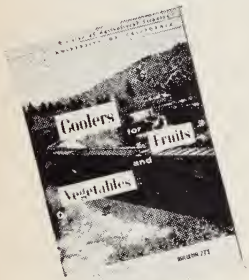

the BULLETIN series . . . designed for an audience of scientists, and for informed laymen interested in new research.

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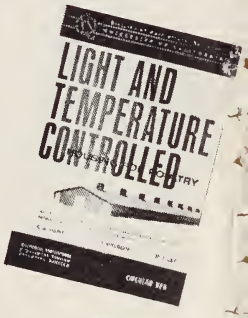

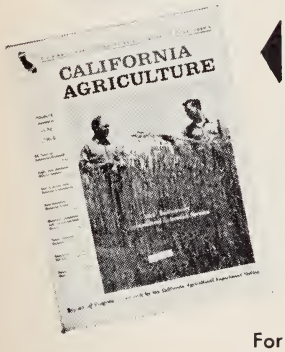

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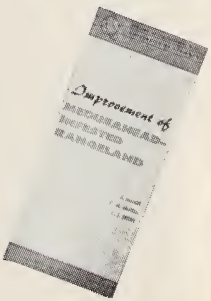

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